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Secular Change in Long Bone Length and Proportion in the United States, 1800–1970

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ABSTRACT We examine secular change in long bone lengths and allometry of Americans dating from the mid-19th century to the 1970s. Skeletal samples were derived from the Huntington Collection, Terry Collection, World War II casualties, and the Forensic Anthropology Data Bank. Regression of bone length on year of birth allowed evaluation of the secular change in bone length. Size was computed as the geometric mean of all bone lengths, and shape as the ratio of each bone to size. These variables were then regressed on year of birth, allowing evaluation of allometric secular change. The results revealed a pattern of change that can be summarized as follows: male secular change is stronger than female, lower limb bone secular change is more pronounced than upper limb bone change, and distal bones change more than proximal bones, particularly in the lower limb. In males, white changes are uniformly higher than black but these differences do not rise to the level of statistical significance. Environmental forces, such as nutrition and disease, are the usual causes of secular changes in overall size. This paper shows that long bone proportions also respond to these same environmental factors. Moreover, the changes in body proportion are likely to be due to allometric consequences of growth changes that occur early in life. Am J Phys Anthropol 110:57–67, 1999.

Secular change in height has been explored in the anthropological as well as the economic historical literature. Factors that affect biological change may be genetic or environmental, and the two are extremely difficult to tease apart. This paper examines biological changes in the long bones of American white and black males and females. If secular change occurs in body size, relationships among different structures may change as well. If allometric secular change occurs, it suggests that various parts of the body respond differently or at different rates to changes in the environment, or reach their genetic potential at different rates. The need to examine the underlying causes of these possible allometric secular changes stimulated the present study.

While secular change in height has been a focus of attention in the anthropological as well as the economic historical literature, little attention has been devoted to changes in bone lengths or in proportions. The question was first investigated by Trotter and Gleser (1951) and then by Meadows and Jantz (1995) and Meadows Jantz (1996). Meadows and Jantz (1995) found allometric changes in the long bones of white and black males, spanning a temporal period from the mid-1800s to 1970. Results indicated that the lower limb bones are positively allometric with stature, meaning that these bones become proportionally longer as stature increases, while the upper limb bones are isometric, meaning that these bones do not

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TABLE 1. Sample size by decade of birth and by element for each group[1]

Decade of birth	White males						White females						Black males						Black females					
	H	R	U	F	T	F	H	R	U	F	T	F	H	R	U	F	T	F	H	R	U	F	T	F
1800–1809							3	2	2	2	2													
1810–1819							3	1	2	2	2	1												
1820–1829	7	4	3	4	5		6	3	4	9	8	4												
1830–1839	6	4	4	5	5	2	5	4	7	9	11	5												
1840–1849	15	14	14	18	21	15	6	2	2	4	4	4	5	5	5	5	5	5	3	3	3	3	3	3
1850–1859	42	38	37	45	51	36	20	22	21	23	24	19	15	16	16	16	14	14	8	8	8	8	8	8
1860–1869	85	82	85	95	98	87	28	24	24	25	28	23	44	44	44	44	44	44	20	20	20	20	20	20
1870–1879	73	74	74	72	76	75	14	12	12	15	14	13	68	67	67	68	68	68	22	23	23	23	22	23
1880–1889	52	52	52	52	52	52	8	8	8	8	8	8	78	79	79	79	79	79	30	30	30	30	30	30
1890–1899	22	22	22	22	22	22	5	4	4	5	5	5	68	68	68	68	68	68	43	42	42	43	42	42
1900–1909	50	47	48	51	53	50	16	15	15	15	15	14	90	88	88	88	89	87	46	46	45	47	46	46
1910–1919	468	459	442	467	467	414	16	16	17	16	14	12	67	67	64	67	65	62	20	20	20	20	20	20
1920–1929	653	646	626	657	653	586	13	11	11	13	13	12	50	49	46	49	50	47	4	4	4	4	4	4
1930–1939	44	43	43	42	43	42	10	13	11	11	10	10	11	9	9	11	11	11	4	4	3	3	4	3
1940–1949	31	34	33	34	32	33	16	15	14	19	18	13	11	10	6	11	10	8	6	6	5	8	6	6
1950–1959	37	29	30	40	40	33	26	25	25	29	25	26	6	5	4	7	6	5	10	9	9	12	10	9
1960–1969	18	17	18	18	17	18	24	20	22	24	24	21	10	10	10	10	10	9	2	2	2	3	2	2
1970–1979	7	5	5	6	5	1	10	8	9	8	3	2	1	1	1	1	1	1	3	3	1	3	1	1

[1] H, humerus; R, radius; U, ulna; F, femur; T, tibia; F, fibula.

change in their proportions as stature changes (Meadows and Jantz, 1995).

Although proportionality was not their focus, Trotter and Gleser (1951) found that stature and bone length among American whites and blacks have changed over time. They pointed out that long bones may be superior to stature for studying secular changes:

> the feasibility of utilizing such measures (long bones) in the study of stature trends is demonstrated and even recommended since the effect of the ageing factor and the need for recorded stature of the subject are eliminated (Trotter and Gleser, 1951, p 439).

Long bones possess several additional advantages over historical records for the study of secular changes: 1) data from both sexes are normally available, while historical records of stature are usually limited to males; 2) measurements can be directly and precisely taken, while historical records of stature are often approximations; 3) skeletal measurements allow examination of changes over longer periods of time; and 4) it is possible to explore changes in shape as well as size. The availability of large numbers of documented skeletons dating from the mid-19th century to the present makes it possible to examine secular change using long bone lengths over a period of 150 years.

MATERIALS AND METHODS

Bone lengths for the six postcranial long bones were available from several sources: 1) Huntington Collection; 2) Terry Collection; 3) World War II (WWII) casualties; and 4) Forensic Anthropology Data Bank. The Terry Collection and WWII measurements were made by Trotter and Gleser (1952). The Huntington Collection was measured by L.M.J. Data collection procedures for the forensic data bank are described in Moore-Jansen et al. (1994), and these data were collected and submitted by forensic anthropologists across the United States. Each of these samples includes identified American whites and blacks, and demographic information was available for each. Meadows and Jantz (1995) and Trotter and Gleser (1951) indicated the need for analyzing whites and blacks separately. Blacks and whites have been shown to differ in bone lengths and proportions (Meadows and Jantz, 1995). These groups are likely to have been exposed to different environments and consequently different environmental changes. Just as these groups respond differently to changes, males and females also respond differently to environmental changes (Stinson, 1985). Consequently, this study examines these groups separately. Table 1 gives

the numbers of bones arranged by group and sex, and decade of birth.

The sampling strategy for each of these samples differed considerably. The Huntington Collection contains mostly immigrants coming through Ellis Island. The Terry Collection consists mostly of indigents from the St. Louis region, although there are a few donated bodies, mostly with later birth dates. The WWII sample is a national sample of mostly young American males who were killed in the Pacific Theater. Their remains were studied by Trotter in Japan during their repatriation. The forensic data bank also contains a national sample, but is biased somewhat toward the Southeast, Northeast, and Southwest. In nearly all cases, a birth date was available from records, or a date of death and age at death allowed computation of year of birth. In a few cases in the forensic data bank, date of death was known and age at death was estimated from the skeleton. In these instances, birth date may be off by a few years, which should matter little in the 150 or so years covered by the study.

Each of the sampling frameworks has its own kind of bias. The Terry Collection contains mainly older individuals of lower socioeconomic status. The military sample is a broad cross section of Americans, but contains only those who passed preinduction physical examinations (Karpinos, 1958). The forensic data bank sample is regionally diverse, but contains approximately 31% of individuals who died by homicide, 7% by suicide, and 8% by accident—all atypical manners of death in the general population.

Maximum length measurements were available for all long bones except the Terry and WWII tibiae, which were measured by Trotter. Maximum length definitions provided by Trotter and Gleser (1952) correspond to standard definitions (Moore-Jansen et al., 1994). Trotter's mismeasurement of the tibia by omitting the malleolus has been identified (Jantz et al., 1994, 1995). Trotter's tibial measurements were adjusted to maximum lengths by adding a constant amount, ranging from 10–13 mm, depending upon group (Jantz et al., 1995; Meadows Jantz, 1996).

Secular change was evaluated by regressing long bone length on year of birth. To detect irregular or cyclical patterns, first-, second-, and third-order polynomials were tested. Individual data were used in the regression so that variation among samples in sample size and distribution of birth years was considered in the tests of significance. Two analyses were conducted. First, raw long bone lengths were regressed on year of birth. For this analysis we used all available bones, whether or not individuals were represented by complete sets. Second, a size variable was computed as the geometric mean of the six bones, and shape variables as the ratio of each bone divided by size (Darroch and Mosimann, 1985). This analysis required complete individuals, resulting in sample sizes averaging about 20% smaller than those given in Table 1. Size and shape variables were then regressed on year of birth.

This method of separating size and shape is preferable to the residual methods often used in growth research (e.g., Bogin and Sullivan, 1986) because it removes isometric size (for a full discussion of ratio and residual methods, see Jungers et al., 1995). The shape variables are therefore not necessarily uncorrelated with size, as required by residual methods. In the present instance, it was clear that if proportions were unchanged, we would observe secular changes in size only. Secular changes in shape variables imply changes in proportion.

Variation among group and sex in the pattern of secular change was examined by testing the equality of regression coefficients. This test was limited to the linear component of each group's regression.

Time series data such as these are often autocorrelated, which can affect parametric significance tests. Autocorrelation was examined using the Durban-Watson test. Autocorrelation was generally low, and none was significant. Therefore, standard parametric tests were justified and were employed throughout.

RESULTS

Probabilities and R^2 of each polynomial term of the regressions of bone lengths on year of birth are presented in Table 2. White

TABLE 2. Linear regression of bone length on year of birth

	White males		White females		Black males		Black females	
	P	R^2	*P*	R^2	*P*	R^2	*P*	R^2
Humerus (N)	1,610		229		525		221	
First order	0.000	0.0218	0.497	0.0020	0.128	0.0044	0.553	0.0016
Second order	0.154	0.0230	0.416	0.0050	0.426	0.0056	0.740	0.0021
Third order	0.001	0.0294	0.551	0.0065	0.080	0.0115	0.073	0.0168
Radius (N)	1,570		206		518		220	
First order	0.000	0.0624	0.004	0.0399	0.000	0.0255	0.263	0.0057
Second order	0.678	0.0625	0.866	0.0401	0.492	0.0264	0.785	0.0061
Third order	0.009	0.0666	0.071	0.0555	0.687	0.0267	0.330	0.0105
Ulna (N)	1,536		210		507		216	
First order	0.000	0.0635	0.041	0.0199	0.000	0.0255	0.925	0.0000
Second order	0.153	0.0647	0.684	0.0207	0.501	0.0263	0.731	0.0006
Third order	0.005	0.0696	0.328	0.0253	0.490	0.0273	0.467	0.0031
Femur (N)	1,628		237		525		227	
First order	0.000	0.0764	0.001	0.0452	0.000	0.0372	0.006	0.0332
Second order	0.415	0.0768	0.402	0.0481	0.579	0.0378	0.935	0.0332
Third order	0.000	0.0864	0.389	0.0511	0.830	0.0378	0.352	0.0370
Tibia (N)	1,639		228		521		218	
First order	0.000	0.0948	0.001	0.0503	0.000	0.0407	0.278	0.0054
Second order	0.736	0.0948	0.669	0.0511	0.400	0.0420	0.686	0.0062
Third order	0.000	0.1050	0.217	0.0575	0.791	0.0421	0.507	0.0083
Fibula (N)	1,467		192		508		217	
First order	0.000	0.0957	0.002	0.0509	0.000	0.0428	0.080	0.0142
Second order	0.600	0.0959	0.480	0.0534	0.560	0.0434	0.952	0.0142
Third order	0.002	0.1018	0.853	0.0536	0.375	0.0449	0.683	0.0149

males exhibited significant change in all six of the long bones for the first- and third-order polynomials. This was the only group to exhibit significant change in the humerus; the first-order and third-order polynomials had *P* values of 0.000 and 0.001, respectively. White males were also the only group to reflect significance for any variable beyond the first-order polynomial. These differences between white males and the other groups may be due to the much larger sample size for white males. Although significant, the third-order term increased the R^2 relatively little, indicating that the major trend in long bone length is linear.

Black males exhibited significant change in the radius and ulna as well as the femur, tibia, and fibula. Although these bone lengths exhibited significant change through time, the R^2 values remained small, the fibula ($R^2 = 0.043$) having the highest correlation with year of birth. Generally, the leg bones were more highly correlated with year of birth than were the bones of the arm. None of the six bones exhibited significance beyond the first-order polynomial.

White females showed a pattern of change in long bone lengths similar to that of black males. The humerus did not exhibit any significant change, but all other long bones did. The correlations between bone lengths and year of birth were slightly higher in this group (R^2 ranging from 0.04–0.05) than in black males; however, these correlations were still quite small.

Black females comprised the most stable group in the present study. The only bone that exhibited significant change over time was the femur ($P = 0.006$, $R^2 = 0.033$). The humerus and fibula showed a weaker secular trend with $P = 0.07$, $R^2 = 0.017$ (third order) and $P = 0.08$, $R^2 = 0.014$ (first order), respectively.

Table 3 shows the linear regression slopes, to provide an indication of rates of secular change for each long bone in all groups. Although white males had a significant cubic regression, only the linear coefficient is presented. This will allow comparison to other groups, since the linear term accounts for most of the secular trend. The lower limb bones showed a more pronounced secular change than the upper limb bones. These changes exhibited a pattern by group and sex: males exceeded females, and whites exceeded blacks. The one exception is the femur, where black females changed at a rate of 0.175 mm per year and white females changed at 0.1 mm per year. White males exhibited rates of change greater than for all

TABLE 3. Slopes of the linear regressions of bone length on year of birth

	White				Black			
	Males		Females		Males		Females	
Bone	b	se	b	se	b	se	b	se
Humerus	0.1044	0.0175	0.0147	0.0217	0.0533	0.0350	0.0245	0.0412
Radius	0.1431	0.0140	0.0591	0.0203	0.1027	0.0280	0.0384	0.0342
Ulna	0.1459	0.0143	0.0440	0.0212	0.1081	0.0296	−0.0035	0.0369
Femur	0.2839	0.0245	0.1040	0.0312	0.2149	0.0478	0.1748	0.0629
Tibia	0.2855	0.0218	0.1023	0.0296	0.2096	0.0447	0.0642	0.0590
Fibula	0.2895	0.0233	0.1083	0.0339	0.2144	0.0451	0.1030	0.0587

b, slope; se, standard error.

TABLE 4. F ratios and probabilities of tests for group and sex differences of regression coefficients of bone length on year of birth

	Whites, male vs. female		Blacks, male vs. female		Males, black vs. white		Females, black vs. white	
Bone	F	*P*	F	*P*	F	*P*	F	*P*
Humerus	9.32	<0.01	0.24	0.62	1.98	0.16	0.04	0.83
Radius	11.52	<0.01	1.88	0.17	1.98	0.16	0.27	0.60
Ulna	13.45	<0.01	4.72	0.03	1.72	0.19	1.79	0.18
Femur	19.26	<0.01	0.25	0.62	1.87	0.17	1.08	0.30
Tibia	23.48	<0.01	3.50	0.06	2.68	0.10	0.35	0.56
Fibula	18.81	<0.01	2.06	0.15	2.53	0.11	0.01	0.94

other groups. The fibula changed at the fastest rate for white males at 0.290 mm per year, but the tibia and femur changed nearly as quickly.

Table 4 presents the results of tests for variation between sexes and groups. It is clear that sex differences exceeded group differences. In whites, all long bones exhibited highly significant sex differences in secular change, the lower limb bones exhibiting greater sex differences than the upper. In blacks, the only bone showing significant sex difference in secular change was the ulna, although the tibia was close to significance. Group differences were not significant in either sex, although they tended to be somewhat greater in males than females.

Figure 1 shows the plots of long bone length on year of birth, using means per decade. The points fall on the mid-decade (e.g., for 1860–1869, the point falls on 1865). The outlying points on the plots are decades represented by very small sample sizes (e.g., for the radius, white females showed a sharp decline in bone length in 1845; however, there was only a single individual in this decade for this group). The plot for the humerus (Fig. 1a) clearly illustrates the increasing trend for males, and the relative stability shown by females. The lines for both female groups overlap considerably throughout time. The plots for the radius and ulna are, as expected, very similar to each other. White males and females and black males all exhibited an upward trend in radius and ulna lengths over time. These plots indicate that black males and females have maintained consistently longer radii and ulnae when compared to same-sex white groups. The one exception was again a result of the small sample for the 1960s for black females.

A comparison of the plots (Fig. 1d–f) for the leg bones shows that the femur, tibia, and fibula all behaved in a similar fashion over time for each of the groups. The plot for the femur (Fig. 1d) shows the upward trend in all groups over time. The female lines overlap for the majority of the period of study, while femur length for black males is consistently longer than white males. The tibia and fibula show a common pattern of black males and females being longer than white males and females, respectively. The female lines for these distal leg bones converge during the decades of the 1890s, 1930s, and 1960s.

Results of the regressions of size and shape variables on year of birth are presented in Table 5. Males exhibited signifi-

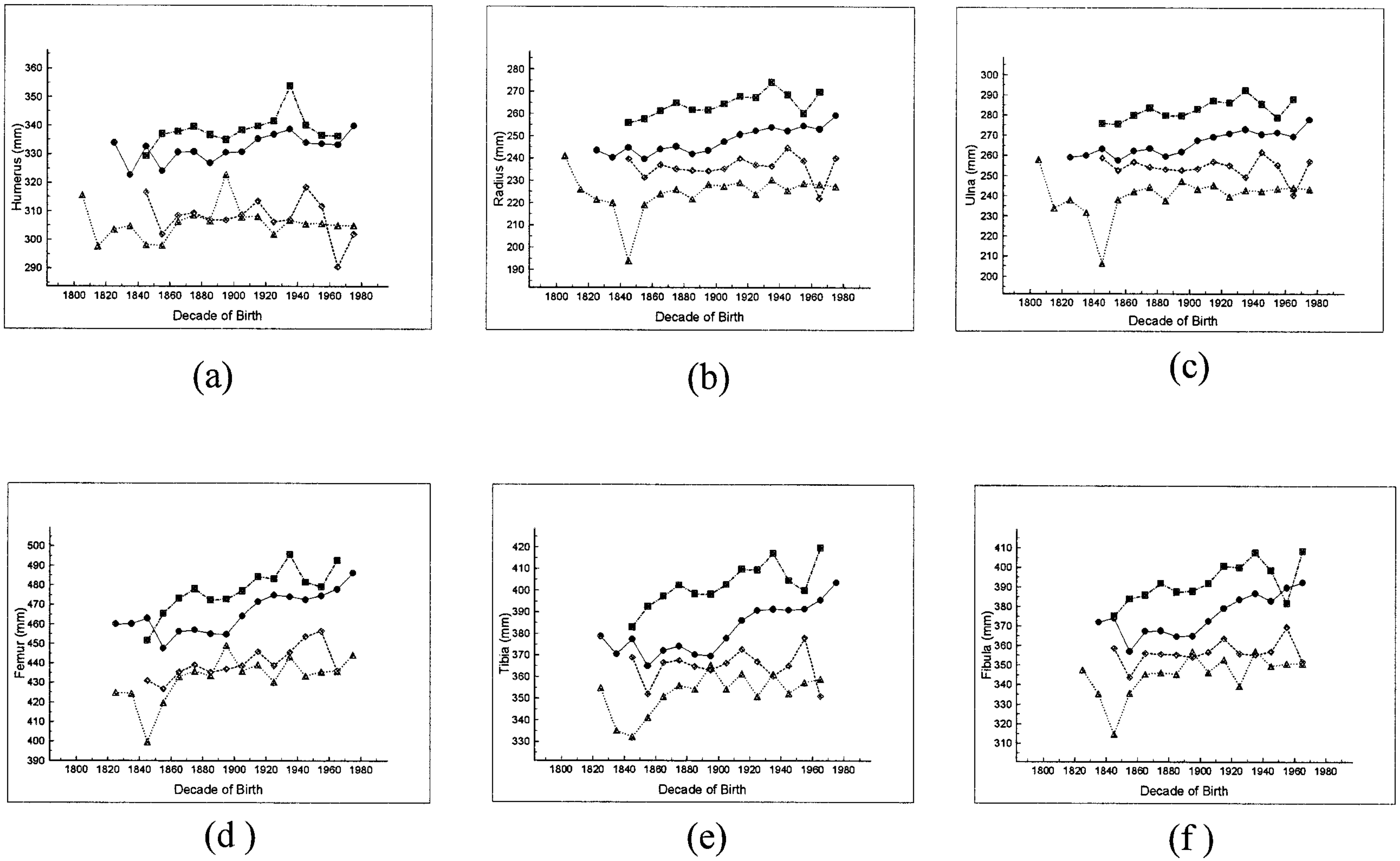

Fig. 1. Plots of mean bone lengths by decade of birth: (**a**) humerus, (**b**) radius, (**c**) ulna, (**d**) femur, (**e**) tibia, and (**f**) fibula. White males, circles; white females, triangles; black males, squares; black females, diamonds.

TABLE 5. Linear regression of size and shape on year of birth[1]

Size	White males		White females		Black males		Black females	
	P	R^2	*P*	R^2	*P*	R^2	*P*	R^2
First order	0.000	0.0632	0.064	0.0222	0.000	0.0285	0.117	0.0117
Second order	0.839	0.0632	0.825	0.0225	0.542	0.0292	0.860	0.0118
Third order	0.004	0.0692	0.327	0.0287	0.425	0.0305	0.301	0.0170
Humerus								
First order	0.000	0.0804	0.064	0.0221	0.000	0.0451	0.482	0.0024
Second order	0.999	0.0813	0.999	0.0249	0.999	0.0463	0.999	0.0027
Third order	0.999	0.0817	0.188	0.0339	0.097	0.0522	0.146	0.0150
Radius								
First order	0.756	0.0001	0.494	0.0031	0.732	0.0002	0.999	0.0000
Second order	0.999	0.0008	0.999	0.0035	0.999	0.0002	0.999	0.0146
Third order	0.015	0.0069	0.999	0.0039	0.999	0.0005	0.026	0.0199
Ulna								
First order	0.171	0.0014	0.227	0.0095	0.511	0.0009	0.011	0.0303
Second order	0.999	0.0017	0.097	0.0167	0.999	0.0017	0.080	0.0459
Third order	0.038	0.0039	0.999	0.0168	0.063	0.0028	0.078	0.0534
Femur								
First order	0.411	0.0005	0.485	0.0032	0.150	0.0043	0.036	0.0209
Second order	0.003	0.0065	0.234	0.0182	0.278	0.0063	0.325	0.0243
Third order	0.268	0.0073	0.233	0.0213	0.125	0.0121	0.999	0.0243
Tibia								
First order	0.000	0.0317	0.539	0.0025	0.002	0.0200	0.875	0.0001
Second order	0.101	0.0331	0.999	0.0031	0.999	0.0200	0.035	0.0155
Third order	0.001	0.0402	0.140	0.0112	0.128	0.0253	0.999	0.0180
Fibula								
First order	0.000	0.0399	0.109	0.0166	0.000	0.0277	0.201	0.0078
Second order	0.001	0.0480	0.999	0.0256	0.999	0.0278	0.095	0.0200
Third order	0.999	0.0495	0.999	0.0256	0.999	0.0279	0.999	0.0200

[1] Sample sizes are: white males, 1,343; white females, 156; black males, 486; black females, 211.

cant change in size over time, as reflected in the long bone analyses presented earlier. The weaker secular changes in female individual bones appear as weaker, nonsignificant secular change in overall size.

Shape reflects a bone's length relative to lengths of all other bones. All of the long bones showed changes in shape over time in white males, while none of the bones showed any change for white females. The humerus exhibited a weak change in shape (*P* = 0.064); however, as previously mentioned, none of the other long bones changed in shape through time. Black males showed a pattern of change in the humerus, tibia, and fibula similar to that seen in white males. Black males exhibited shape change over time in the humerus, but no change in the distal bones of the arm. Contrary to this, the femur did not change shape, while the distal bones of the leg did change over time. Of interest, black females exhibited a reversal of the trend exhibited in black males. The humerus did not change in shape over time, but the radius and ulna did change over time. The femur also showed change in shape over time, but the tibia and fibula did not.

Figure 2 shows the plots for the regression of size and shape for the humerus, ulna, tibia, and fibula. Both male groups exhibited a general decline in relative humerus length through time (Fig. 2a). This reflects the lack of increase in length of the humerus relative to all of the other long bones. Note that the humerus is relatively longer in whites than in blacks.

Black females' change in ulna shape was also exhibited as a decline or negative slope (Fig. 2b). The line for black males is nearly horizontal and shows few irregularities through time. The lines for white males and females are more irregular and show no trend. A pattern opposite to that seen in the humerus shape is reflected in the ulna, where blacks generally have relatively longer ulnae compared to whites. The only exception to this is seen in the 1930s, when black females rapidly decreased. This decrease was immediately followed by a rapid increase in the next decade.

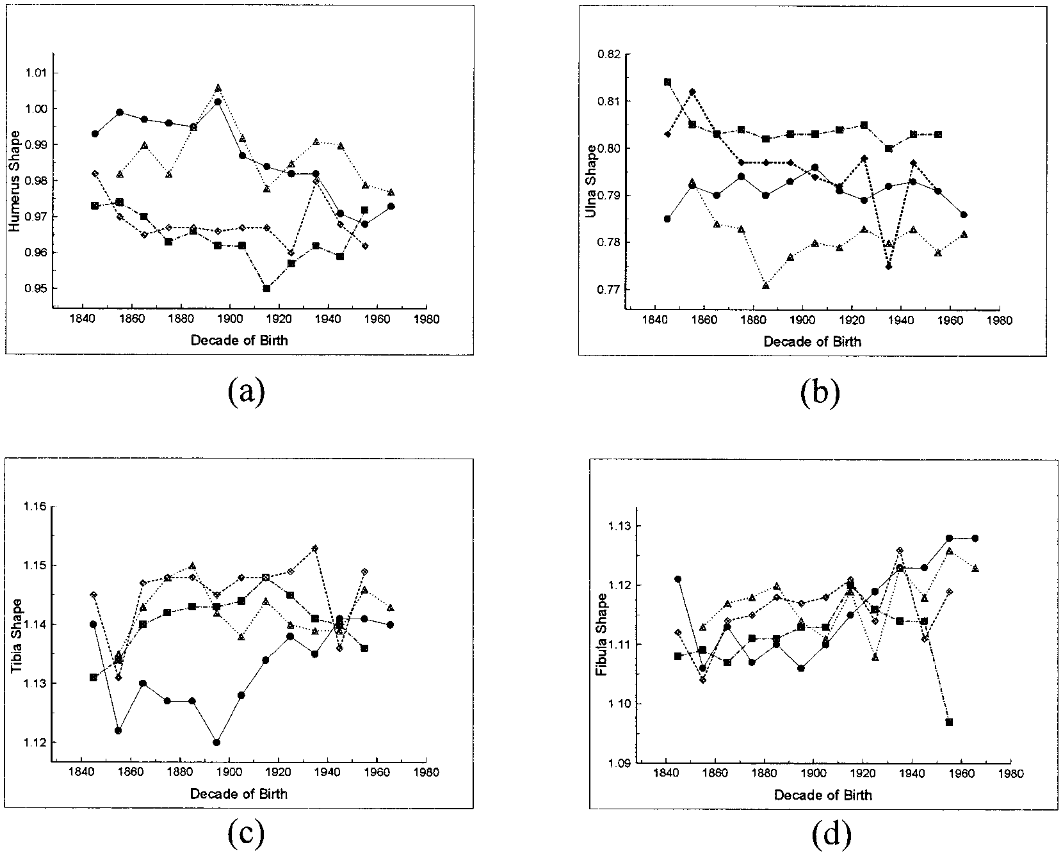

Fig. 2. Plots of bone shape by decade of birth: (**a**) humerus, (**b**) ulna, (**c**) tibia, and (**d**) fibula. White males, circles; white females, triangles; black males, squares; black females, diamonds.

The plots for tibia and fibula shapes (Fig. 2c,d) illustrate a striking result of this study, namely that white males are very different from the other three groups. In all of the other comparisons, either race or sex groups tended to cluster together, but this is not the case with the tibia. The line clearly illustrates that for white males, the tibia is relatively shorter than for any of the other groups. White females and black males and females maintained a similar shape across time, particularly during the decades of the 1850s and 1940s, where these three groups converge. The white males also converged with the others during the 1940s. The plot for the fibula (Fig. 2d) shows that white males fluctuated during the 19th century, but then they exhibited a rapid increase during the 20th century. A comparison of the white male lines for tibia and fibula shows that both bones experienced similar changes; however, the tibia is strikingly shorter relative to the other bones.

DISCUSSION

Secular change in height has been extensively documented using historical data (e.g., Komlos, 1990, 1994; Steckel, 1987, 1995; Steegmann, 1985, 1986, 1991; Fogel, 1986a,b, 1995; Floud et al., 1990; Floud, 1994). Our results using long bone lengths are similar to those obtained from heights, mainly for white males, over the last 150 years. Like height, the lower limb bones reflect the mid–late 19th century trough, followed by recovery in the early 20th century and continued secular increase through the 1960s and 1970s. This finding shows

that long bone lengths, particularly the lower limb bones, can serve as a proxy for stature. As such they can be used to examine questions where stature data are not normally available. In the present instance, that would include examination of changes in proportion which accompany changes in stature, and variation between sexes and to some extent between blacks and whites as well.

The results reveal a pattern of change that can be summarized as follows: male secular change is stronger than female, lower limb bone secular change is more pronounced than upper limb bone change, and distal bones change more than proximal bones, particularly in the lower limb. In males, white changes are uniformly higher than black, but these differences do not rise to the level of statistical significance.

The greater secular change seen in males may reflect the differences between the sexes in sensitivity to environmental changes, as has been pointed out previously (Greulich, 1976; Wolanski and Kasprzak, 1976; Siniarska, 1996; Stinson, 1985; Stini, 1969). There remains some controversy concerning the existence of the sex difference in environmental sensitivity. Wolanski and Kasprzak (1976) pointed out that the female body is more resistant to environmental change, while males respond to the slightest change. Stinson (1985) agreed that males are more subject to greater prenatal mortality and growth retardation, but argued that the postnatal evidence, particularly for secular changes, is less convincing.

Our results offer convincing evidence of sex differences in secular response to environmental changes, particularly for whites. Similar results were obtained by Wu (1994), using height data from the Pittsburgh area. During the period 1890–1945, males gained over twice as much height as females in both blacks and whites. The principal caveat in our results concerns sampling. These samples would not meet the criteria of Roche (1979) for identifying secular changes. In general, the female and male samples were obtained from similar sources, except for the period between 1910–1930, where there are large numbers of WWII casualties that do not have female counterparts.

Although the direction of white-black differences is consistent in males, we could not accept the hypothesis of a difference in secular change. This finding is itself important, if one supposes that in general, blacks' environments were less favorable than those of whites throughout much of the time period considered here. The ability of black populations to maintain heights equal to or greater than those of whites under generally worse circumstances has been shown in several different instances. Garn et al. (1973) showed that black children exceed white children in height, in direct contrast to the socioeconomic differences between the two groups. During the 19th century, even slaves exhibited little evidence of reduced stature (Steckel, 1987). Our data show (Fig. 1) that blacks generally have longer bones than whites, and that there is a positive secular trend for those blacks born prior to emancipation, at least for males. Like whites, blacks exhibited a decline in long bone length during the late 19th century, but maintained greater bone lengths throughout.

The one result obtained in the present study that is unavailable from historical records of stature concerns changes in proportions. Generally, lower limb bones exhibit rates of change greater than the for the upper limb bones (see Table 3 for slopes). These findings take on additional significance when considered in relation to the static allometric scaling of limb bones to stature in adults. We have shown (Meadows and Jantz, 1995) that the lower limb bones scale positively to stature, while the upper limb bones scale negatively. Hence, taller individuals have relatively longer lower limbs and relatively shorter upper limbs. This pattern of static allometry apparently extends to secular allometry; as long bone lengths, and presumably height, increase, lower limbs are relatively longer and upper limbs are relatively shorter.

Meadows and Jantz (1995) also found that the tibia and fibula are more positively allometric than the femur in relation to stature. That pattern of static allometry extends to secular allometry in the form of relative increases in tibia and fibula length. The greater response of distal bones has been observed in the opposite context of

greater reduction from malnutrition in nonhuman primates (Fleagle et al., 1975).

The forces driving secular changes in height are usually considered to be changes in nutritional and disease environment. However, changes in adult stature have been found to correlate with many variables, including income distribution (Baten, 1996a), milk production (Baten, 1996b), general nutrition and temperature (Steegmann, 1985), gross domestic product and infant mortality (Floud, 1994), birth weight and maternal prepregnancy weight (Alberman et al., 1991), and postneonatal mortality (Schmidt et al., 1995). Use of stature as an indication of economic circumstances rests on a relationship between stature and standard of living. Steckel (1995) stated it essentially as follows: stature is the outcome of nutritional intake minus demands. Demands are principally in the form of disease and work.

In a variable as complex as stature, the situation is likely to be more complicated than the simple equation of height = intake - demands. The pattern of secular change beginning in the early 19th century seems to be very general and to cut across socioeconomic lines. Even the severely disadvantaged seem to participate in the secular gains and losses in height. The example of Steckel (1987) of American slaves was noted above. In addition, Steegmann (1991) observed no stunting in a mid-19th century poorhouse sample representing the most impoverished societal level. The great depression showed no discernible effect on height, and in fact height increase was faster during the 1930s than during the period from 1890–1945 (Wu, 1994). Even more remarkable is that skeletal growth continues to occur under conditions of malnutrition so severe that there is no weight gain (Bogin, 1979).

It is likely that influences acting early in development have been underestimated in the discussion of secular changes in adult height. Some research shows that secular changes are established by early childhood (Bock and Sykes, 1989). Environmental influences have their greatest impact from between the ages of 6 months and 3 years, and possibly again during adolescence (Martorell et al., 1992; Tanner et al., 1956). Alberman et al. (1991) found that prenatal variables account for a large fraction of secular change. Our results do not bear directly on the question of timing, but the observation that secular changes in size result in shape changes that would be predicted from allometric scaling relationships, some of which may be set in motion very early (Buschang, 1982; Watkins and German, 1992), strongly suggests early rather than late influences. It is therefore possible that much of the secular variation in adult height results from prenatal influences. Based on the results of this study, it is clear that the cumulative environmental conditions that Americans were exposed to during the prenatal period and the first 3 years of life have continued to improve over the past two centuries.

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LITERATURE CITED

Alberman E, Filakti H, Williams S, Evans SJW, Emanuel I. 1991. Early influences on the secular change in the adult height between the parents and children of the 1958 birth cohort. Ann Hum Biol 18:127–136.

Baten J. 1996a. Der Einfluss von regionalen Wirtschaftstrukturen auf den biologischen Lebenstandard. Vierteljahrschr Sozial Wirtschaftgesch 83:180–213.

Baten J. 1996b. Der Einfluss von Einkommensverteilung und Milchproduktion auf die regionalen Unterschiede des Ernährungsstandards in Preussen um die Mitte des 19 Jahrhunderts. Arch Sozialgesch 36:69–83.

Bock RD, Sykes R. 1989. Evidence for continuing secular increase in height within families in the United States. Am J Hum Biol 1:143–148.

Bogin B. 1979. Monthly changes in the gain and loss of growth in weight of children living in Guatemala. Am J Phys Anthropol 51:287–291.

Bogin B, Sullivan T. 1986. Socioeconomic status, sex, age, and ethnicity as determinants of body fat distribution for Guatemalan children. Am J Phys Anthropol 69:527–535.

Buschang PH. 1982. Differential long bone growth of children between 2 months and 11 years of age. Am J Phys Anthropol 58:291–295.

Darroch JN, Mosimann JE. 1985. Canonical and principal components of shape. Biometrika 72:241–252.
Fleagle JG, Samonds KW, Hegsted DM. 1975. Physical growth of cebus monkeys, *Cebus albifrons*, during protein or calorie deficiency. Am J Clin Nutr 28:246–253.
Floud R. 1994. The heights of Europeans since 1750: a new source for European economic history. In: Komlos J, editor. Stature, living standards, and economic development: essays in anthropometric history. Chicago and London: University of Chicago Press. p 9–24.
Floud R, Wachter K, Gregory A. 1990. Height, health, and history: nutritional status in the United Kingdom, 1750–1980. Cambridge: Cambridge University Press.
Fogel RW. 1986a. Physical growth as a measure of the economic well-being of populations: the eighteenth and nineteenth centuries. In: Falkner F, Tanner JM, editors. Human growth: a comprehensive treatise. New York: Plenum Press. p 263–281.
Fogel RW. 1986b. Nutrition and the decline in mortality since 1700: some preliminary findings. In: Engerman SL, Gallman RE, editors. Long-term factors in American economic growth. Chicago: University of Chicago Press. p 439–555.
Fogel RW. 1995. Anthropometric history: notes on the first two decades of a new field of research. In: Hauspie R, Lindgren G, Falkner F, editors. Essays on auxology. Welwyn Garden City, UK: Castlemean Publications. p 271–284.
Garn SM, Clark DC, Trowbridge FL. 1973. Tendency toward greater stature in American black children. Am J Dis Child 126:164–166.
Greulich WW. 1976. Some secular changes in the growth of American-born and native Japanese children. Am J Phys Anthropol 45:553–568.
Jantz RL, Hunt DR, Meadows L. 1994. Maximum length of the tibia: how did Trotter measure it? Am J Phys Anthropol 93:525–528.
Jantz RL, Hunt DR, Meadows L. 1995. The measure and mismeasure of the tibia: implications for stature estimation. J Forensic Sci 40:758–761.
Jungers WL, Falsetti AB, Wall CE. 1995. Shape, relative size, and size-adjustments in morphometrics. Yrbk Phys Anthropol 38:137–161.
Karpinos BD. 1958. Height and weight of selective service registrants processed for military service during World War II. Hum Biol 30:292-–321.
Komlos J. 1990. Height and social status in eighteenth-century Germany. J Int Hist 20:607–621.
Komlos J, editor. 1994. Stature, living standards, and economic development: essays in anthropometric history. Chicago: University of Chicago Press.
Martorell R, Rivera J, Kaplowitz H, Pollitt E. 1992. Long-term consequences of growth retardation during early childhood. In: Hernandez M, Argente J, editors. Human growth: basic and clinical aspects. Amsterdam: Elsevier. p 143–149.
Meadows L, Jantz R. 1995. Allometric secular change in the long bones from the 1800s to the present. J Forensic Sci 40:762–767.
Meadows Jantz L. 1996. Secular change and allometry in the long limb bones of Americans from the mid 1700s through the 1970s. Ph.D. Dissertation, University of Tennessee, Knoxville.
Moore-Jansen PH, Ousley SD, Jantz RL. 1994. Data collection procedures for forensic skeletal material, 3rd ed. Knoxville, TN: Department of Anthropology, University of Tennessee, Knoxville, Report of Investigations no. 48.
Roche AF. 1979. Secular trends in human growth, maturation, and development. Monogr Soc Res Child Dev 44:3–27.
Schmidt IM, Jorgensen MH, Michaelsen KF. 1995. Height of conscripts in Europe: is postneonatal mortality a predictor? Ann Hum Biol 22:57–67.
Siniarska A. 1996. Sexual dimorphism index (SDI) of body height as an indicator of economic changes in Yucatan, Mexico. Am J Phys Anthropol [Suppl 22] :215.
Steckel RH. 1987. Growth depression and recovery: the remarkable case of American slaves. Ann Hum Biol 14:111–132.
Steckel RH. 1995. Stature and standard of living. J Econ Lit 33:1903–1940.
Steegmann AT. 1985. 18th century British military stature: growth cessation, selective recruiting, secular trends, nutrition at birth, cold and occupation. Hum Biol 57:77–95.
Steegmann AT. 1986. Skeletal stature compared to archival stature in mid-eighteenth century America: Ft. William Henry. Am J Phys Anthropol 71:431–435.
Steegmann AT. 1991. Stature in a mid-19th century poorhouse population: Highland Park, Rochester, New York. Am J Phys Anthropol 85:261–268.
Stini WA. 1969. Nutritional stress and growth: sex difference in adaptive response. Am J Phys Anthropol 31:417–426.
Stinson S. 1985. Sex differences in environmental sensitivity during growth and development. Yrbk Phys Anthropol 28:123–147.
Tanner JM, Healy MJR, Lockhard RD, Mackenzie JD. 1956. Aberdeen growth study: part 1. The prediction of adult body measurements from measurements taken each year from birth to 5 years. Arch Dis Child 31:372–381.
Trotter M, Gleser GC. 1951. Trends in stature of American whites and Negroes born between 1840 and 1924. Am J Phys Anthropol 9:427–440.
Trotter M, Gleser GC. 1952. Estimation of stature from long bones of American whites and Negroes. Am J Phys Anthropol 10:463–514.
Watkins MA, German RZ. 1992. Ontogenetic allometry of ossified fetal limb bones. Growth Dev Aging 56:259–267.
Wolanski N, Kasprzak E. 1976. Stature as a measure of effects of environmental change. Curr Anthropol 17: 548–552.
Wu J. 1994. How severe was the Great Depression? Evidence from the Pittsburgh region. In: Komlos J, editor. Stature, living standards, and economic development: essays in anthropometric history. Chicago and London: University of Chicago Press. p 129–152.